BULLETIN NO. 13.

Forms for Concrete Construction

Association of
American Portland Cement Manufacturers

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(BULLETIN No. 13)

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Read before the Third Annual Convention of the National Association of Cement Users

Association of
American Portland Cement Manufacturers
LAND TITLE BUILDING
Philadelphia

Forms for Concrete Construction

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Recent failures in reinforced concrete construction cannot be cast one side and forgotten with the passing comment so frequently heard, that the accident was due merely to poor construction or too early removal of forms. The reasons for every failure should be thoroughly investigated by experts to prevent recurrence of similar accidents.

"Poor construction" and "forms," although frequently guilty, are by no means the only culprits. Just so long as men who know nothing of the first principles of mechanics are permitted to design concrete structures, and just so long as irresponsible contractors are engaged to erect them, the list of accidents will increase in startling numbers. It is the men—not the inanimate lumber—who are to blame in every case. However, granting its danger under ignorant hands, reinforced concrete as a whole must not be condemned for failures due to improper conditions any more than brick should be rejected as a building material for apartment houses because of the collapse of several unfinished buildings in New York city two years ago through disregard of frost action upon the mortar.

Failures in concrete buildings may be attributed to:

(1) Imperfect design; especially through neglect of essential details in locating the reinforcing metal, and through the adoption of too low a factor of safety.

(2) Poor materials; such as cement which does not properly set up, or sand which is too fine or which has an excess of clay, loam or other impurities.

(3) Faulty construction; from improper proportioning, mixing or placing, or too early removal of forms.

(4) Weak forms.

A disregard of such important principles is frequently criminal negligence, and yet in at least one case under my observation an examination of the structure and the materials after a collapse in which a number of lives were lost showed the design, materials and construction to be all so faulty that it was impossible to decide positively which of the four causes named above was the primary reason for the failure.

In this paper it is proposed to treat only of the design, construction and removal of forms.

GENERAL RULES FOR FORM CONSTRUCTION.

Kind of Lumber.—The selection of the lumber must be governed by the character of the work and the local market. White pine is best for fine facework, and quite essential for ornamental construction cast in wooden forms. For ordinary work, however, even for the panels, white pine is apt to be too expensive, and spruce, fir, Norway pine or the softer qualities of Southern pine must be substituted for it. Some of these woods are more liable to warp than white pine, but they are generally stiffer and thus better adapted for struts and braces.

Kiln dried lumber is not suitable for form construction because of its tendency to swell when the wet concrete touches it. Very green lumber, on the other hand, especially Southern pine which does not close up quickly when wet, may give trouble by joints opening. Therefore, the middle ground, or, in other words, partially dry stuff, is usually best.

Finish and Thickness of Lumber.—Either tongued-and-grooved or bevel-edged stuff will give good results for floor and wall panel forms, and is preferable to square-edged stuff. A smoother surface may be attained at first with the tongued-and-grooved stock than with square or bevel edge and there is less trouble with opening joints, but it is more expensive because of the waste in dressing, and if the forms are used many times there is greater tendency to wear at the joints. Even for rough forms plank planed one side may be economical to cheapen the cost of cleaning. Studs should always be planed one side to bring to size.

The thickness of lumber varies with different contractors, some using 1 in., others 1½ in., while a few employ 2 in. stuff

even for panels. (These are commercial thicknesses measured before planing.) For ordinary walls $1\frac{1}{2}$ in. stuff is good, although for heavy construction where derricks are used 2 in. is preferable, while for small panels 1 in. boards are lighter and easier to handle. For floor panels 1 in. boards are most common, although if the building is eight stories high or over, 1 in. stuff of soft wood is likely to be pretty well worn out before the top of the building is reached, and the under surface of the concrete will show the wear badly. For sides of girders either 1 in. or $1\frac{1}{2}$ in. is sufficient, while 2 in. is preferable for the bottoms of girders. Column forms are generally made of 2 in. plank.

DETAILS OF FORM CONSTRUCTION.

Certain general rules are applicable to all kinds of forms. Strength, simplicity and symmetry are three fundamental principles of design. The necessity for strength is obvious. Economy in concrete construction consists in quickly erecting and moving the forms and in using them over and over again.

The design of the concrete members should recognize the forms. A slight excess of concrete sometimes may be contributed to save carpenter work. Frequently beams may be designed of such widths as to use dimension widths of lumber without splitting.

Columns may be of dimensions to avoid frequent remaking. Recesses may be made the thickness of a board or a plank. To permit ready cleaning of dirt and chips from the column forms before laying the concrete, at least one prominent contractor provides a door at the bottom of each of them.

In building construction the forms must be designed so that the column forms and also the bottom of beam molds are all independent of the slabs. The forms may thus be left a longer time upon members subjected to the greater stress.

The sides of the beam forms should be held tightly together, by wedges or clamps, to prevent the pressure of the concrete springing them away from the bottom boards. Hardwood wedges at top or bottom of each strut are useful when setting and removing it, and also permit testing to make sure

that there is no deflection of the beam or slab. For this purpose some contractors loosen the wedges twenty-four hours in advance of the struts. In general it is preferable to use comparatively light joists, such as 2 in. x 8 in. or 2 in. x 10 in., with frequent shores rather than to use lumber which is heavier to handle.

If forms are to be used but once, or must be taken apart when removed, it is sometimes practicable to use only a few partially driven nails so that they can be withdrawn without injury to the lumber. It is very difficult to convince house carpenters that the pressure of concrete will hold temporary panel boards in place with scarcely any nailing.

Alignment is another item of importance, since it is here that a great deal of time may be wasted by inexperienced or incompetent carpenters. Such workmen may err either on the side of poor alignment or more careful alignment than the structure requires. Mr. W. J. Douglas* suggests as a general rule the allowance of "⅜-inch departure from established lines on finished work and 2 inches on unfinished work."

In removing forms the green concrete must not be disturbed by prying against it. This seems so obvious as to need no emphasis, but I have known first-class carpenters to actually attempt to straighten a wall which was an inch out of line the day after the concrete was laid by prying the forms over. The wall was straightened, but by a different process from that proposed by the carpenter—the concrete was relaid.

Forms for facework should be tightly put together, it being advisable in some cases to close the joints and holes by mortar, putty, plaster-of-Paris, sheathing paper or thin metal. This is not, as is commonly supposed, to prevent loss of strength by the cement which flows out with the water, but rather to prevent the formation of voids or stone pockets in the finished surface.

Crude oil is one of the best materials to prevent adhesion of the concrete to the forms, though linseed oil, soft soap and various other greasy substances are also employed for this

*_Engineering News_, Dec. 20, 1906. p 648.

purpose. The oil or grease should be thin enough to flow and fill the grain of the wood.

If the forms are to be left on until the concrete is hard, there is little danger of the concrete sticking to them if they are wet thoroughly with water before the concrete is laid instead of being greased. In any case, if concrete adheres to the forms it should be thoroughly cleaned off before resetting; even then it is apt to stick again in the same place.

DESIGN OF FORMS.

"Rule-of-thumb" layout of forms in the field is being superseded by design in the drawing-room. In building construction where the forms form a large percentage of the cost of the building, and where a failure in the forms may cause loss of life, it is especially necessary to treat this question from an engineering standpoint, and many of the best concrete contractors now design their forms as carefully as the dimensions of the concrete members.

If a minimum quantity of lumber is to be used consistent with the deformation allowed, it follows that the dimensions and spacing of the supporting lumber must be actually computed from the weight or pressure against the sheeting. For columns and for walls where a considerable height of wet concrete is to be placed at once, the pressure may be calculated as a liquid. Mr. W. J. Douglas* assumes that the concrete is a liquid of half its own weight, or 75 pounds per cubic foot.

In ordinary walls, where the concrete is placed in layers, computation is not usually necessary, since general experience has shown that maximum spacing for 1-inch boards is 2 feet, for 1½-inch plank is 4 feet, and for 2-inch plank is 5 feet. Studding generally varies from 3 x 4 inch to 4 x 6 inch, according to the character of the work and the distance between the horizontal braces or waling. 4 x 4 inch is the most useful size.

Floor forms are better based upon an allowable deflection than upon strength, in order to give sufficient stiffness to prevent partial rupture of the concrete or sagging beams.

In calculating we must add to the weight of the concrete itself—i. e., to the dead load—a construction live load which

***Engineering News*, Dec. 20, 1906, p. 646.*

may be assumed as liable to come upon the concrete while setting. Definite units of stress must also be assumed in the lumber.

I would suggest the following basis for computation, these being values which I have adopted for use:

(1) Weight of concrete, including reinforcement, 154 lb. per cu. ft.

(2) Live load, 75 lb. per sq. ft. upon slab, or 50 lb. per sq. ft. in figuring beam and girder forms.

(3) For allowable compression in struts use 600 to 1200 lb. per sq. in., varying with the ratio of the size of the strut to its length. (See table below.) If timber beams are calculated for strength, use 750 lb. per sq. in. extreme transverse fiber stress.

(4) Compute plank joists and timber beams by the following formula, allowing a maximum deflection of ⅛ inch:

$$d = \frac{3}{384} \quad \frac{Wl^3}{EI} \qquad (1)$$

and

$$I = \frac{bh^3}{12} \qquad (2)$$

in which

d = greatest deflection in inches;
W = total load on plank or timber;
l = distance between supports in inches;
E = modulus of elasticity of lumber used;
I = moment of inertia of cross-section of plank or joist;
b = breadth of lumber;
h = depth of lumber.

The formula is the ordinary formula for calculating deflection except that the coefficient is taken as an approximate mean between 1/384 for a beam with fixed ends and 5/384 for a beam with ends simply supported.

For spruce lumber and other woods commonly used in form construction, E may be assumed as 1,300,000 lb. per sq. in.

Formula (1) may be solved for I, from which the size of joist required may be readily estimated.

The weight of concrete per cubic foot is somewhat higher than is frequently used, but is none too much where a dense mixture and an ordinary percentage of steel is used. For very rough calculation, however, it is frequently convenient to remember that 144 lb. per cubic foot is equivalent to the product of the dimensions of the beam in inches times a length of one foot.

The suggested live load is assumed to include the weight of men and barrows filled with concrete, and structural material which may be piled upon the floor, not including, however, the weight of piles of cement or sand or stone, which should never be allowed upon a floor unless it is supported by concrete sufficiently strong to bear the weight, or by struts under all the floors below.

The units for stress in struts are somewhat higher than in timber construction because the load is a temporary one. The extreme variation given is due to the fact that when a column or strut is longer than about sixteen times its smallest width there is a tendency to bend, which must be prevented, either by bracing it both ways or allowing a smaller load per square inch. For struts ordinarily used the following stresses may be assumed for different heights:

Length of Strut	Safe Strength of Wood Struts in Forms for Floor Construction. Pounds per Sq. In. of Cross-Section.			
	3″ x 4″	4″ x 4″	6″ x 6″	8″ x 8″
14 ft.		700	900	1100
12 ft.	600	800	1000	1200
10 ft.	700	900	1100	1200
8 ft.	850	1050	1200	1200
6 ft.	1000	1200	1200	1200

Bracing both ways will, of course, reduce the length of a long strut.

If the concrete floor is comparatively green, the load must be distributed by blocking, preferably of hard wood. At the top of the strut provision must be made against crushing of the

wood of the plank or cross-piece. Ordinary soft wood will stand without crushing only about 700 lb. per sq. in. across the grain, so if the compression approaches this figure brackets must be inserted or hard-wood cleats used.

TIME TO MOVE AFTER PLACING.

The best contractors have definite rules for the minimum time which the forms must be left in ordinary weather, and then these times are lengthened for changes in conditions according to the judgment of the foreman.

Conference with a number of prominent contractors in various parts of the country indicates substantial agreement in the minimum time to leave forms. As a guide to practice the following rules are suggested, these following in the main the requirements of the Aberthaw Construction Company:

Walls in mass work: one to three days, or until the concrete will bear pressure of the thumb without indentation.

Thin walls: in summer, two days; in cold weather, five days.

Slabs up to 6 feet span: in summer, six days; in cold weather, two weeks.

Beams and girders and long span slabs: in summer, ten days or two weeks; in cold weather, three weeks to one month. If shores are left without disturbing them the time of removal of the sheeting in summer may be reduced to one week.

Column forms: in summer, two days; in cold weather, four days, provided girders are shored to prevent appreciable weight reaching columns.

Conduits: two or three days, provided there is not a heavy fill upon them.

Arches: of small size, one week; for large arches with heavy dead load, one month.

All of these times are, of course, simply approximate, the exact time varying with the temperature and moisture of the air and the character of the construction. Even in summer, during a damp, cloudy period, wall forms sometimes cannot be removed inside of five days, with other members in proportion. Occasionally, too, batches of concrete will set abnormally slow, either because of slow setting cement or impurities in the sand.

and the foreman and inspector must watch very carefully to see that the forms are not removed too soon. Trial with a pick may assist in reaching a decision.

Beams and arches of long span must be supported for a longer time than short spans because the dead load is proportionately large and therefore the compression in the concrete is large even before the live load comes upon it.

The general uncertainty and the personal element which enters into this item emphasize the necessity for some more definite plan for insuring safety. The suggestion has been made that two or three times a day a sample of concrete be taken from the mixer and allowed to set on the ground under the same conditions as the construction until the date when the forms should be moved. These sample specimens may be then put in a testing machine to determine whether the actual strength of the concrete is sufficient to carry the dead and construction loads. Even this plan does not provide for the possibility of an occasional poor batch of concrete, so that watchfulness and good judgment must also be exercised.

EXAMPLES OF FORM DESIGN.

I have selected a number of illustrations of typical modern form construction.

The centers of an 8-foot conduit used by the T. A. Gillespie Company in the Pittsburg Filtration System is shown in Fig. 1.

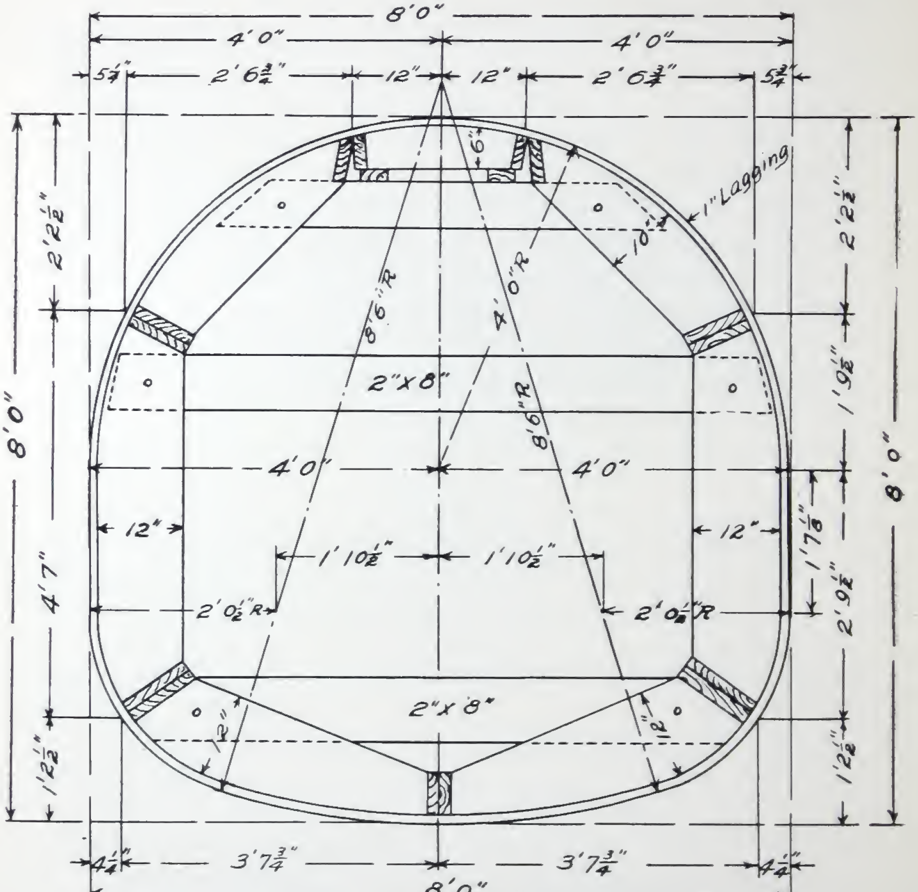
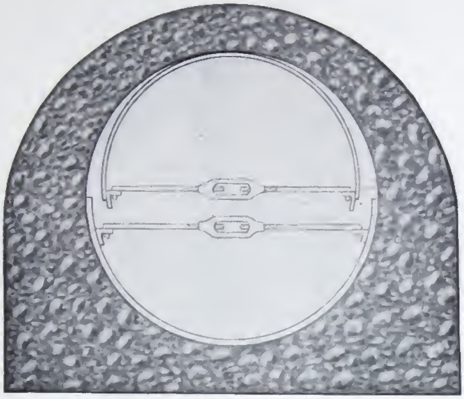


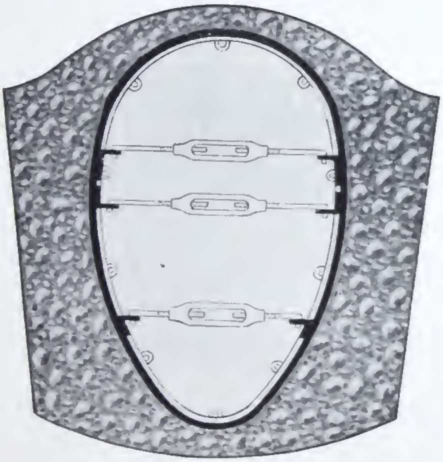
FIG. 1.—Center for 8 Foot Conduit.

You will notice that the form is built in sections, bolted together, so as to be easily taken apart.

The patented Blaw centering is illustrated in Fig. 2. The shell is of steel with turnbuckles provided to collapse the



"BLAW" CENTERS COLLAPSED



"BLAW" CENTERS IN POSITION

FIG. 2.

metal, as shown in the upper section of the figure.

In the Pittsburg filter galleries a very large number of columns were erected for supporting the groined arch roof. Many of these columns were molded in steel centering shown in Fig. 3, this being economical because of the number of

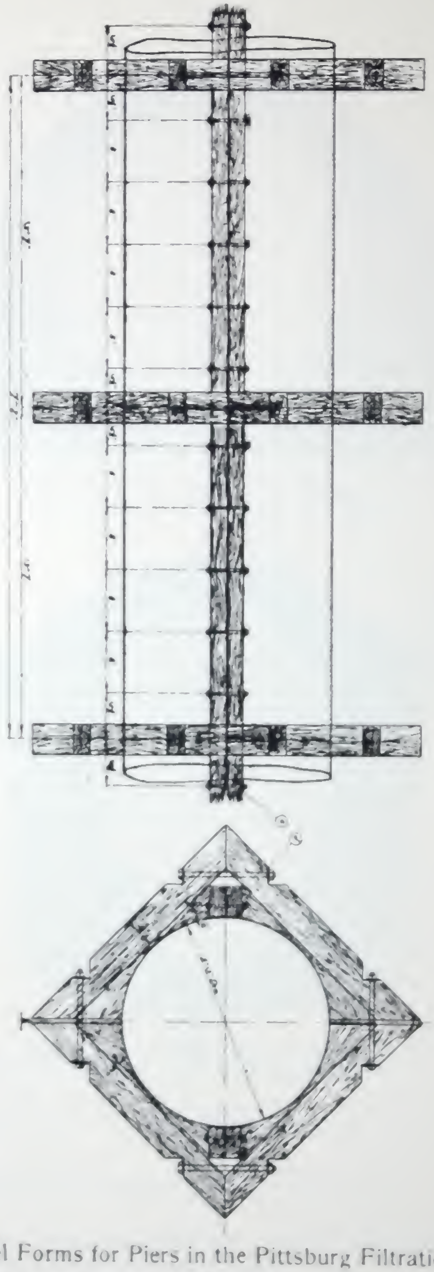


FIG. 3.—Steel Forms for Piers in the Pittsburg Filtration Gallery.

times it could be used over and over.

A more common style of column forms is that employed in the erection of the Harvard Stadium, as shown in Fig. 4.

FIG. 4.—Molds for Columns at Harvard Stadium. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

The slotted form of clamp does not give such stiff centering as another type, shown in Fig. 12.

In Waltham, Mass., a concrete reservoir or standpipe 100 ft. in diameter by 42 ft. high has recently been constructed under the direction of Mr. Bertram Brewer, City Engineer. The forms designed by the contractors, Simpson Brothers Corporation, are shown in Figs. 5 and 6.

FIG. 5.—Forms for Concrete Reservoir, Waltham, Mass.

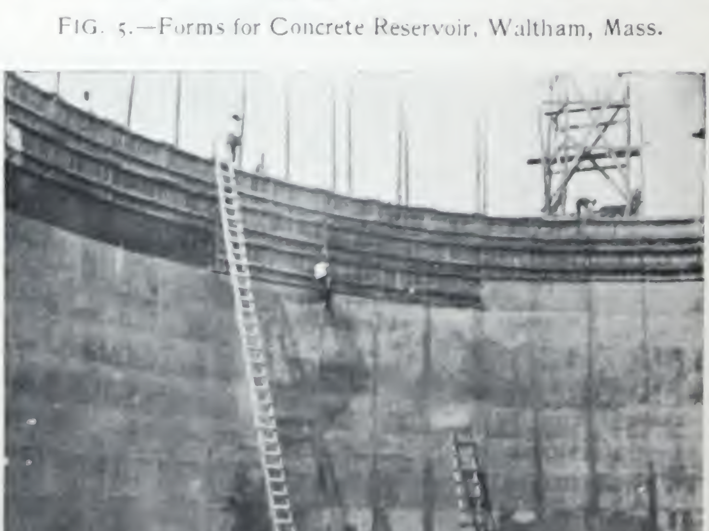


FIG. 6.—Forms for Concrete Reservoir, Waltham, Mass.

Fig. 7 illustrates the construction of a heavy wall where the ties consist of wire twisted to hold the side forms in place.

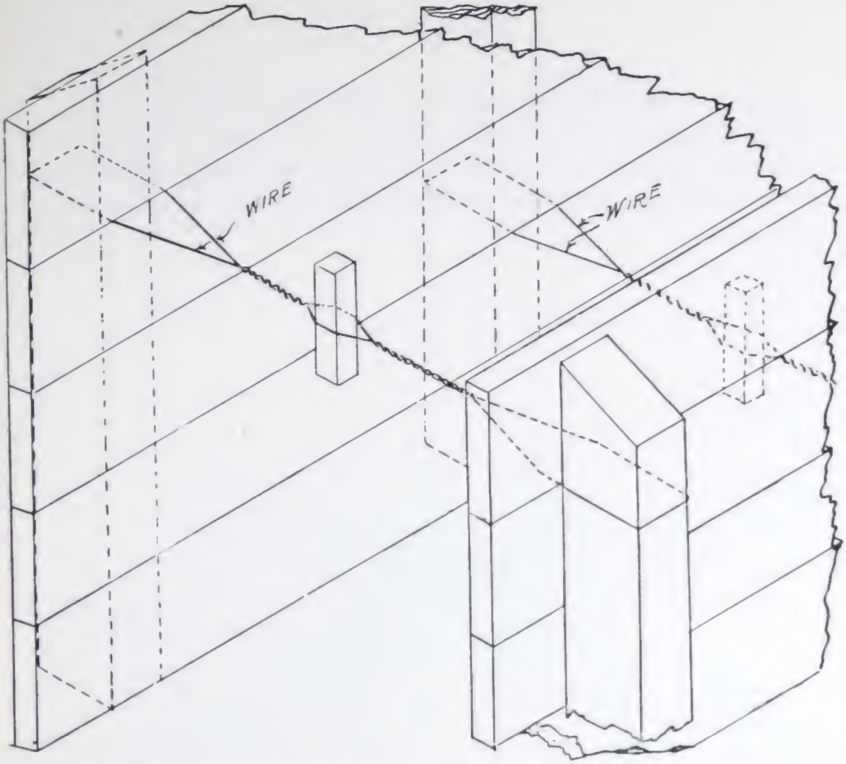


FIG. 7.—Form for Heavy Wall. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

A simple form of construction for a low foundation wall is given in Fig. 8.

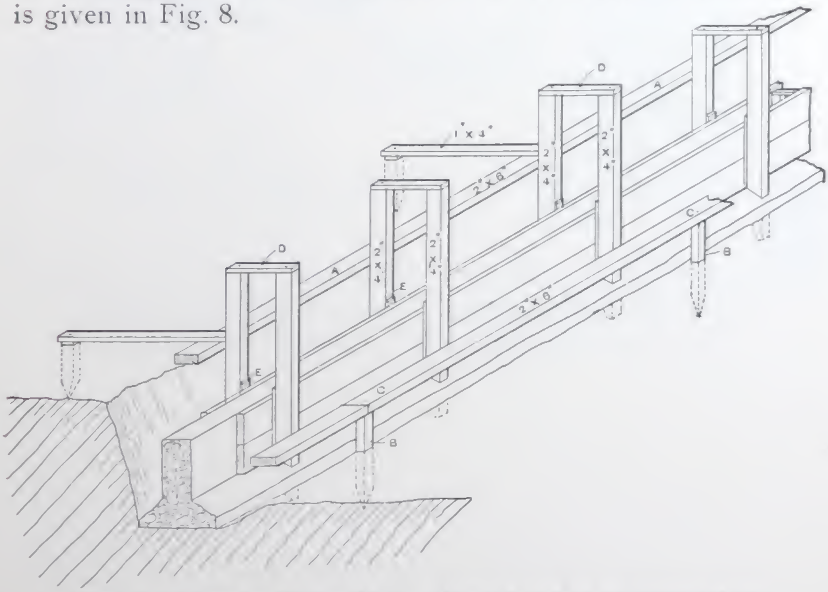


FIG. 8.—Form for Cellar Wall. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

Fig. 9 illustrates a common form for building a wall of greater height. As soon as a section is completed the bolts are loosened and the slotted form of clamp or brace originally designed by Mr. E. L. Ransome permits it to be readily moved upward.

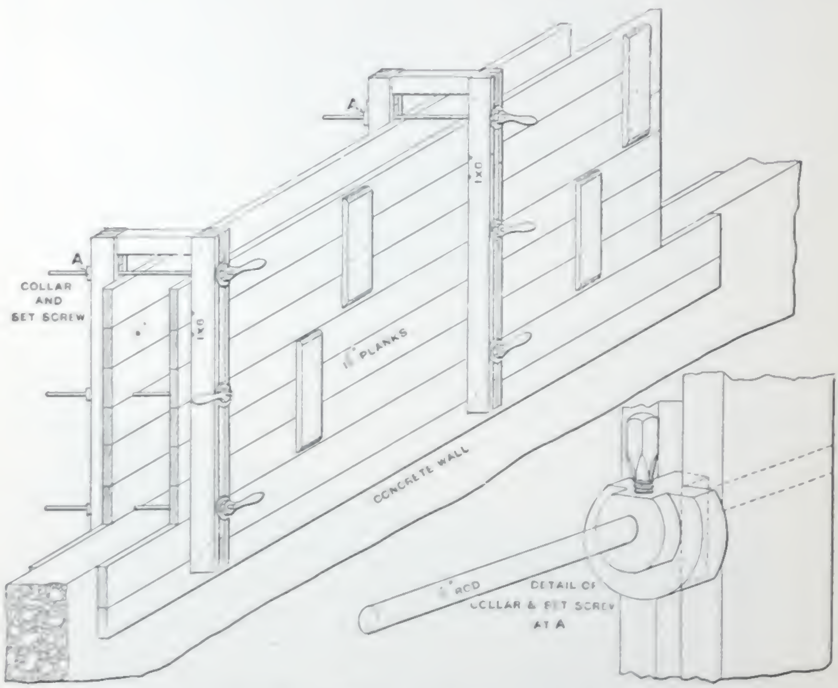


FIG. 9.—Movable Wall Forms. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

Forms for hollow walls are shown in Fig. 10.

A style of wall construction has been designed and patent applied for by Mr. S. H. Lea, using for the forms metal lathing which has first been plastered on the outside. (See Fig. 11.)

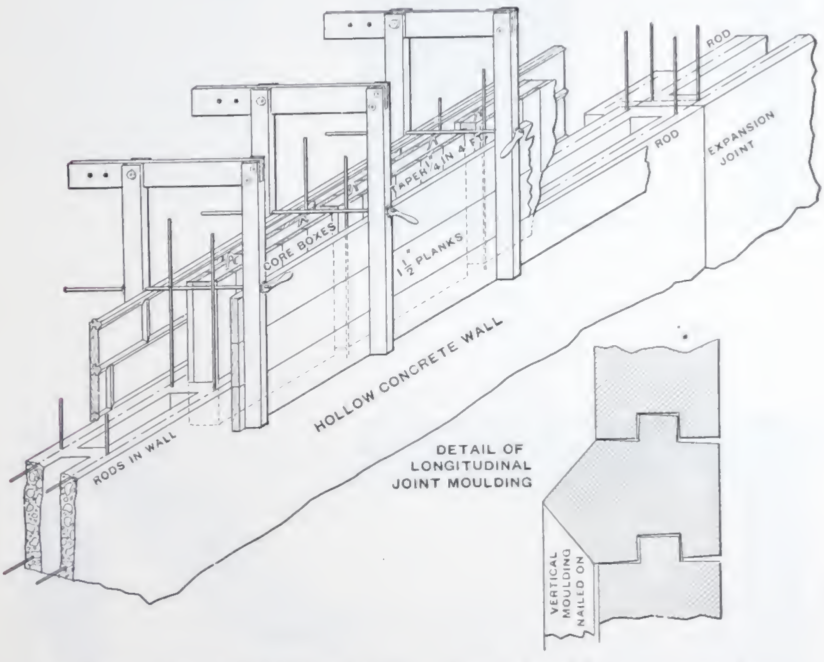
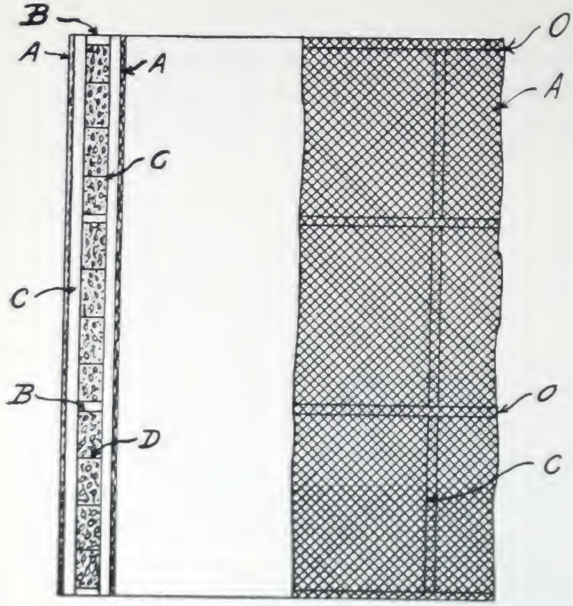


FIG. 10.—Forms for Hollow Walls. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")



EXPLANATION.

A =	Wire Fabric.
B =	Spacing Bar.
C =	Vertical Member.
D =	Separator.
O =	Horizontal Member.

A frame of the desired form is erected of structural steel and covered with wire fabric as shown. A coating of cement or mortar is then applied to the outside of the wire fabric which, upon hardening, forms a shell of the desired outline, which may be filled in with concrete. This method of construction does not require the use of forms or molds, thus effecting a great saving in material and labor, besides affording a strong, well-finished structure. It may be employed in building dams, retaining walls, culverts and other structures.

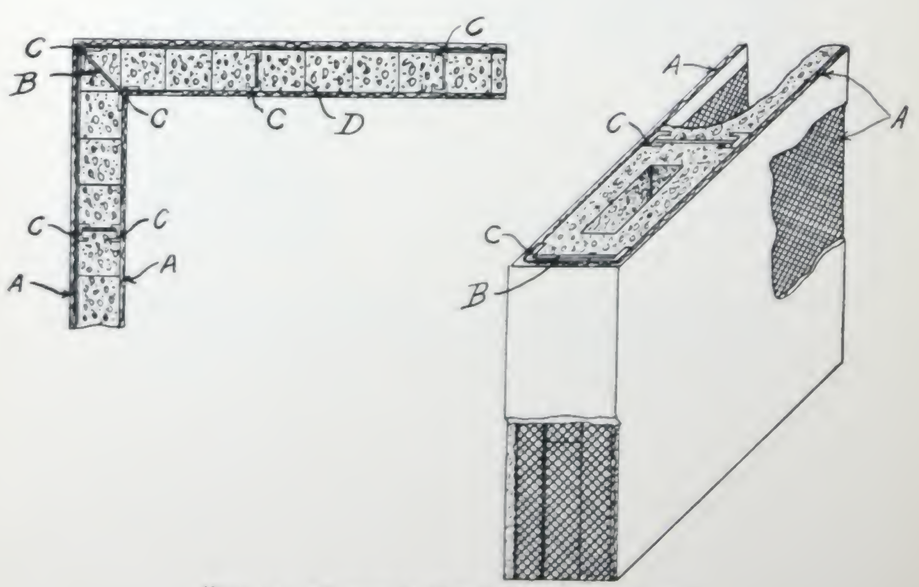


FIG. 11.—Concrete—Metal Wall Construction.

Beam and column forms such as are used in ordinary building construction are shown in Fig. 12. This is a common

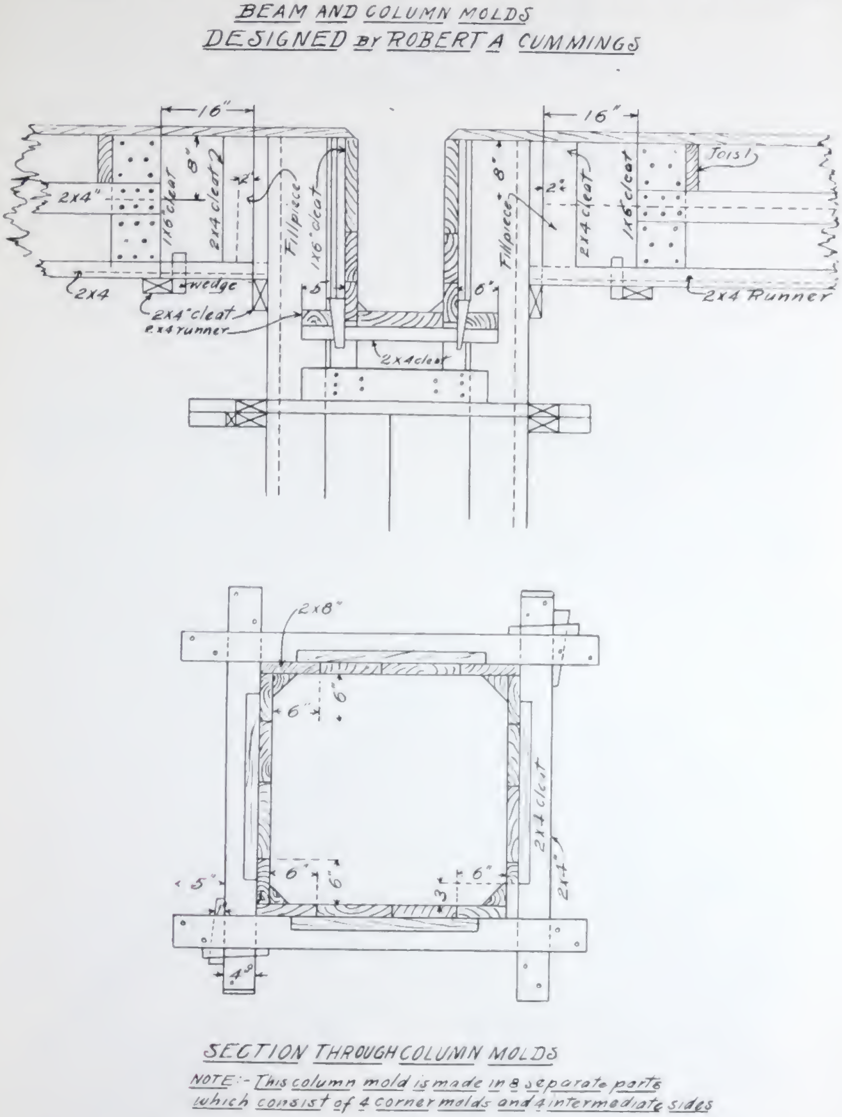


FIG. 12.—Typical Forms in Building Construction.

type with certain features designed by Mr. Robert A. Cummings, from whose drawings the sketch has been made. To hold the sides of the beam forms against the bottom board Mr. Cummings uses a 2 in. x 4 in. runner with wedges against it. The column form shown in the same figure is provided with wedges, which permit very firm and solid construction.

A clamp which is much used by the Ferro-Concrete Construction Company, of Cincinnati, is shown in Fig. 13.

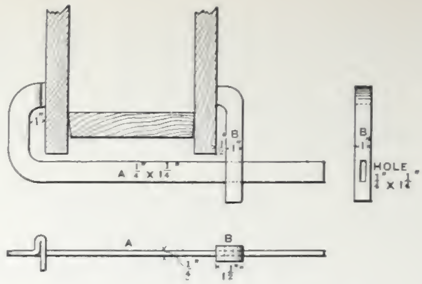


FIG. 13.—Clamp for Beam of Small Column Form. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

A somewhat different type of beam and slab forms has been designed by Mr. Benjamin Fox. The forms for each panel are made in two sections and supported at the center so that they may be dropped without disturbing the bottom plank of the beams and girders. The beams and girders are stiffened by 6 in. x 8 in. and 8 in. x 8 in. timbers placed underneath them and supported by posts varying in size from 4 in. x 4 in. to 8 in. x 8 in., according to the load to be carried.

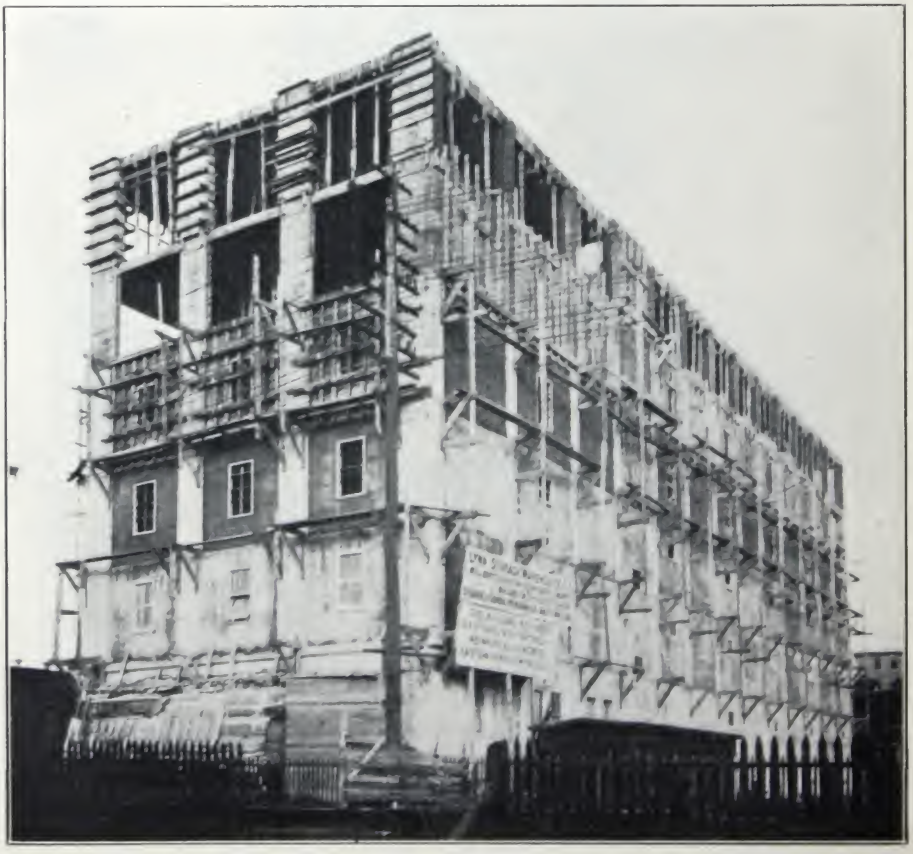


FIG. 14.—Panel Form Construction in Storage Warehouse, Lynn, Mass.

Wall panels in a concrete building are most cheaply constructed after the columns are built. Practical methods as adopted by the Eastern Expanded Metal Company, of Boston, are shown in Fig. 14. It also shows quite clearly the other portions of the form construction.

Fig. 15 is a photograph of the pouring of a slab in a sand mold at the Harvard Stadium by methods adopted by the builders, The Aberthaw Construction Company.

FIG. 15—Pouring Seat Slab of Harvard Stadium. (Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced.")

(We are indebted to *The Concrete Engineering* for the use of cuts Nos. 1, 2, 5, 6, 11 and 14.)

The following is a list of papers which have been printed by the Association of American Portland Cement Manufacturers, Land Title Building, Philadelphia; copies of which may be obtained by addressing as above:

Bulletin No. 1. "Concrete Building Blocks."

Bulletin No. 2. "The Possibilities of Concrete Construction from the Standpoint of Utility and Art."

Bulletin No. 3. "Sand for Mortar and Concrete."

Bulletin No. 4. "Notes on Cement Testing."

Bulletin No. 5. "Irregular Methods of Testing Cement."

Bulletin No. 6. Out of print.

Bulletin No. 7. "The Making and Driving of Corrugated Concrete Piles."

Bulletin No. 8. Out of print.

Bulletin No. 9. "Methods of Testing and Some Peculiarities of Cement."

Bulletin No. 10. "Decoration of Concrete with Colored Clays."

Bulletin No. 11. "Cost Reduction of Reinforced Concrete Work."

Bulletin No. 12. "The Progress and Logical Design of Reinforced Concrete."

Bulletin No. 13. "Forms for Concrete Construction."

"Standard Methods of Testing and Specifications for Cement."

"Concrete Construction—Its Fireproof Qualities."

"Results of Tests"—Made in our Laboratory during the World's Fair, St. Louis, Mo., 1904.

"Concrete Review"—Semi-Monthly Publication.

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